Arctic Upper Ocean Studies

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LONG-TERM GOALS

My goals are to investigate and understand the turbulent transfer of momentum, heat, salt, and other scalar contaminants in naturally occurring boundary layers of the ocean, and to apply this knowledge to understanding air-ice-ocean interaction in polar regions.

OBJECTIVES

Objectives of the project include (i) gathering and analyzing turbulence data from the ocean boundary layer (OBL) under sea ice; (ii) developing techniques, including both new instrumentation and analysis methods, for determining turbulent fluxes in the boundary layer; (iii) combining measurements and theory (including numerical modeling) for concise descriptions of turbulent boundary layer scales; and (iv) using the results to develop parameterizations of important boundary layer processes for large scale numerical models of the sea ice/upper ocean system.

APPROACH

I have developed systems for measuring vertical turbulent fluxes of momentum, heat, and salt in the ocean boundary layer under drifting sea ice by direct covariance of the respective quantities with vertical velocity. Methods for measuring current include orthogonal triads of small mechanical current meters, and three-axis acoustic current meters, both forward sound path Doppler shift (FSI) and nonintrusive backscatter (SonTek). The current meters are mounted near Sea-Bird temperature and conductivity sensors (both ducted and microstructure) in turbulence instrument clusters mounted at several levels on rigid masts. The masts may then be lowered to any level within the upper 120 m of the ocean. The turbulence measurements, nearly unique for ocean boundary layer environments, are then used to determine properties and scales of OBL turbulence.

Measurements are interpreted in the context of boundary layer theory developed around measured flow scales. Of particular value is the empirical observation that the length scale associated with vertical turbulent tranfer (mixing length) is inversely proportional to the wavenumber at the peak of the weighted (slope) spectrum of vertical velocity.

WORK COMPLETED

Work comleted in FY 1999 includes:

(1) SHEBA ocean turbulence mast data analysis. I developed software for quality control and database management for the year long data set from the SHEBA project. The data have been highly condensed and made available for use by SHEBA affiliated investigators on the JOSS data catalog as of September, 1999. A paper on ice/ocean fluxes and turbulent exchange coefficients is under preparation, planned for a special JGR section.

2. SCICEX 98 CTD analysis. I am combining a analysis of sail CTD, surface station CTD, and

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XCTD data from the 1998 Hawkbill cruise with SHEBA summer data to address the problem of spatial and temporal disposition of solar energy in the upper ocean under pack.

3. 1999 SCICEX Drift Station. In collaboration with J. Morison, UW Polar Science Center, I staged a project from the SCICEX 1999 support ice station, which included upper ocean turbulence measurements, periodic CTD stations, and continuous position recording. A data report combining position, CTD, and turbulence data is under preparation.

4. Fjord fast ice boundary layer studies. I carried out a small project with the assistance of students from University Courses on Svalbard to measure heat, salinity, and momentum fluxes with a 3-axis acoustic current in a frozen fjord. We were able to measure consistent flux values in very low energy tidal flows.

5. Invited talks and lectures. I gave invited lectures at (a) the AMS annual meeting, Dallas; (b) the SHEBA/FIRE Workshop, Tucson; (c) University Courses on Svalbard, Longyearbyen; (d) University of Alaska, Fairbanks; and (e) Goddard Space Flight Center, Greenbelt. I also made presentations at the Fall AGU meeting, San Francisco; the SEARCH Workshop, Seattle; the US/Norway Workshop on Svalbard, Longyearbyen; and the OAII All Hands Meeting, Virginia Beach.

RESULTS

The extremely fresh mixed layer observed during the early part of the SHEBA drift from October, 1997 to late January, 1998, indicated intense melting during the 1997 summer and suggested that the albedo feedback mechanism was very active during that melt season (McPhee et al., 1998). This underlined the importance of understanding the disposition of solar energy in the ice/upper ocean system, both spatially and temporally. The combination of a complete summer record from the SHEBA drift station during 1998 with a “snapshot,” near synoptic XCTD survey from the USS Hawkbill cruise during August, 1998, has provided an important perspective on this problem .The SCICEX cruise track and SHEBA drift trajectory on shown together in Fig. 1. The submarine made its closest approach to SHEBA on August 5, 1998.

We have found from several projects measuring turbulent ocean heat flux directly in both the Arctic Ocean and Weddell Sea (e.g., McPhee et al., 1999), that flux is proportional to the product of friction velocity (u_{*0}, square root of Reynolds stress) and departure of the mixed layer from its freezing temperature, $\delta T = T_{ml} - T_f(S_{ml})$. Furthermore, there is typically not much correlation between u_{*0} and δT (i.e., they respond at different frequencies), so that temperature elevation is a pretty good indicator of the heat flux. Fig. 2A is a contour plot of δT in the upper 60 m during the XCTD section indicated by the arrow in Fig. 1. In the southern part of the section, which is over the bathymetric highland of the Northwind Rise- Chukchi Cap complex, there is relatively warm water just below the mixed layer. Farther north, this layer disappears, so that the only source of heat near the surface is from insolation. Fig. 3A plots near surface δT as a function of distance along the section. While there are rather large excursions along the track, a definite trend from south to north is apparent, with the minimum value of δT occurring near the north pole, and an increasing trend as the vessel headed south into the eastern Arctic.

The lower panel of Fig. 3 is the time series of near surface δT observed at the SHEBA station. The

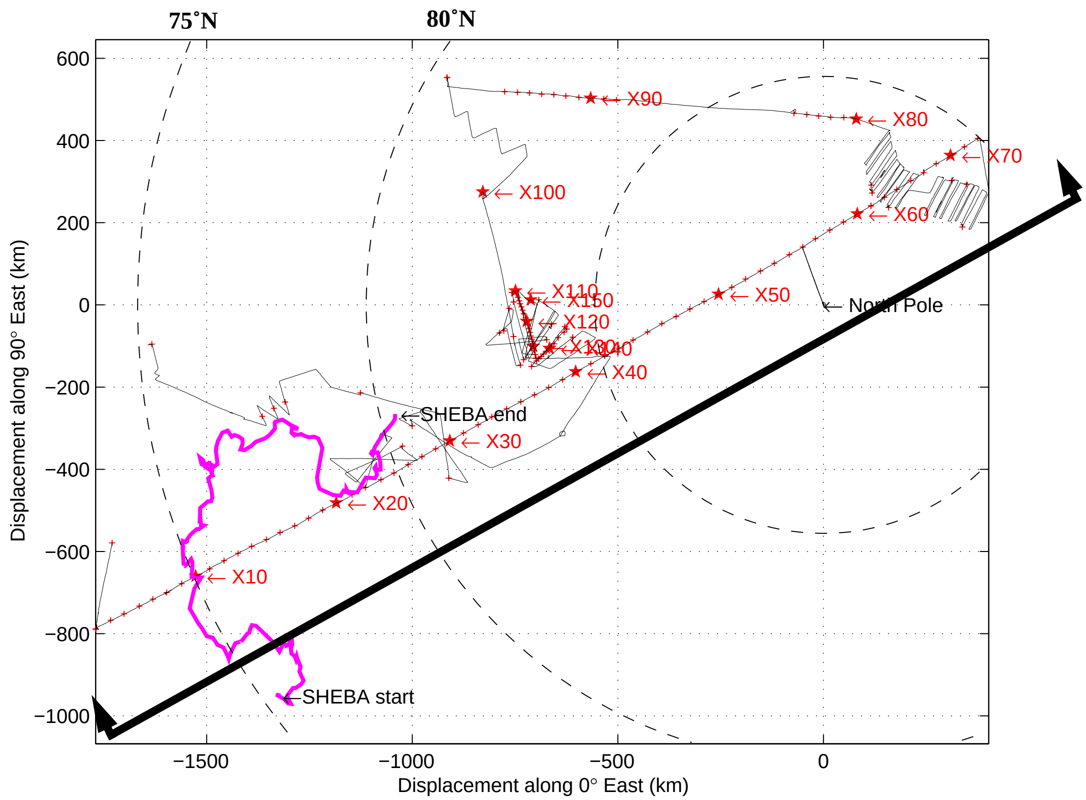

Figure 1. Cruise track of the USS Hawkbill during the August SCICEX mission (black) along with the entire SHEBA drift trajectory (magenta). Numbered expendable XCTD stations are shown in red.

two records agree pretty well at the point of closest approach. The combination of data in Figs. 3A and B thus provides a first-order description of the distribution of solar heating of the Arctic mixed layer as a function of time at over a relatively narrow zonal band (Fig. 3B), and as a near syoptic snapshot during a week in early August (Fig. 3A). In order to get the ocean heat flux part of the surface energy balance right, numerical models of sea ice should be able to reproduce the broad features of Fig. 3.

Going to nearly the opposite end of the spectrum of ocean scales (basin to turbulence), we were able to measure for the first time turbulent ice/ocean fluxes in very low energy flows in a fjord covered by fast ice near Longyearbyen, Svalbard. We measured vertical turbulent heat and salinity flux about 1 m below the ice during three tidal maxima (with mean currents between 2-3 cm s^{-1}). Mean values of u_{*0} were similar. In the first tidal maximum, the departure of mean water temperature from freezing was slightly higher and the turbulent heat flux ($\rho c_p \langle w'T' \rangle$), was about twice as large as in the following cycles, though still very small (~1.2 W m^{-2}). This was corroborated by a corresponding increase in negative salinity flux from the first to later cycles, as a result of increased ice growth rate in the cooler water temperatures. While it is premature to claim that we actually measured differences in heat flux of a small fraction of a watt per square meter, the data are internally consistent and corroborated by considerations of the energy and mass balance at the ice/ocean interface.

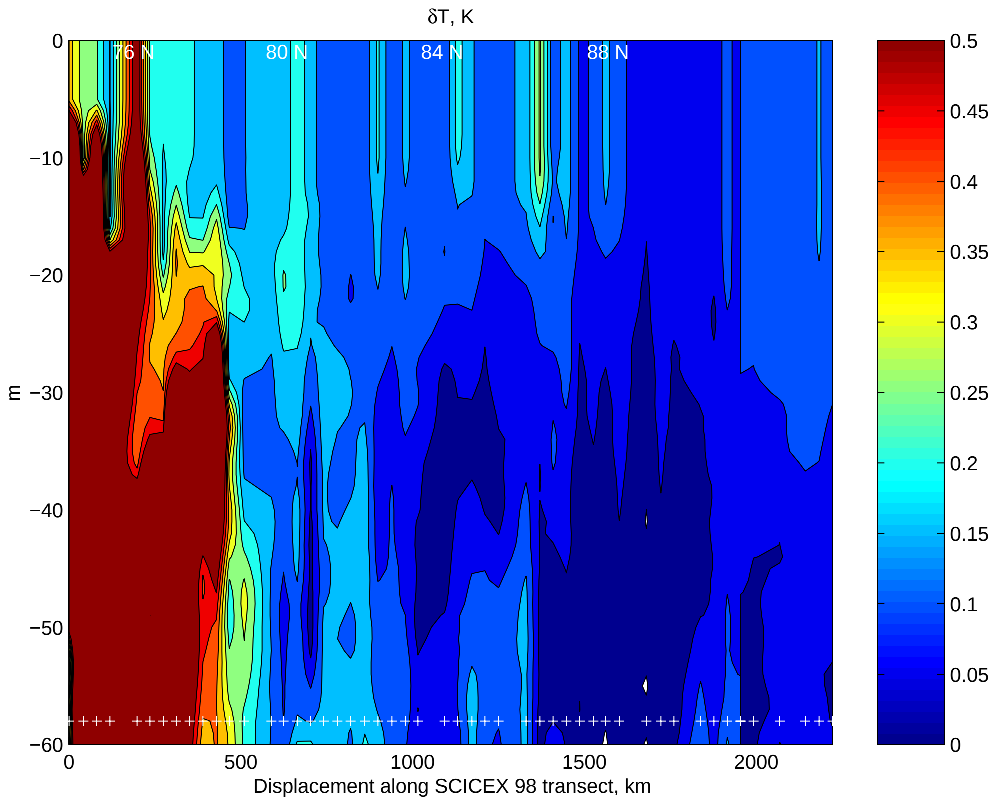

Figure 2. Contour plot of temperature, expressed as departure from freezing, from the SCICEX 98 submarine XCTD section indicated by the heavy arrow in Fig. 1. Note that the section extends beyond the north pole into the eastern Arctic

IMPACT/APPLICATION

Research into basic questions of how the ocean boundary layer works has wide application ranging from detailed studies of ice/ocean interaction to bottom boundary layer flow in estuarine environments to ocean parameterization in global circulation models. My ice/ocean heat flux parameterization, for example, has been incorporated into the PIPS 3.0 operational ice model (W. Maslowski, pers. comm.). Relevant Naval programs include High Latitude Dynamics (Code 322HL), Ocean Modeling and Prediction Program (322OM), Physical Oceanography Program (Code 322 PO).

TRANSITIONS

As the SHEBA and SCICEX 99 turbulence data sets are examined in detail, better defined exchange coefficients for ice/ocean interactions will evolve. Future plans include in depth time series analysis including *empirical mode decomposition.* I believe that the small scale measurements near the ice/ocean interface may help resolve fundamental issues of exchange across that interface, that are not currently well understood.

RELATED PROJECTS

I am working closely with co-PIs J. Morison, D. Martinson, and T. Stanton on SHEBA ocean physics analysis. I am also cooperating closely with D. Kadko, J. Morison, and graduate student Dan Hayes

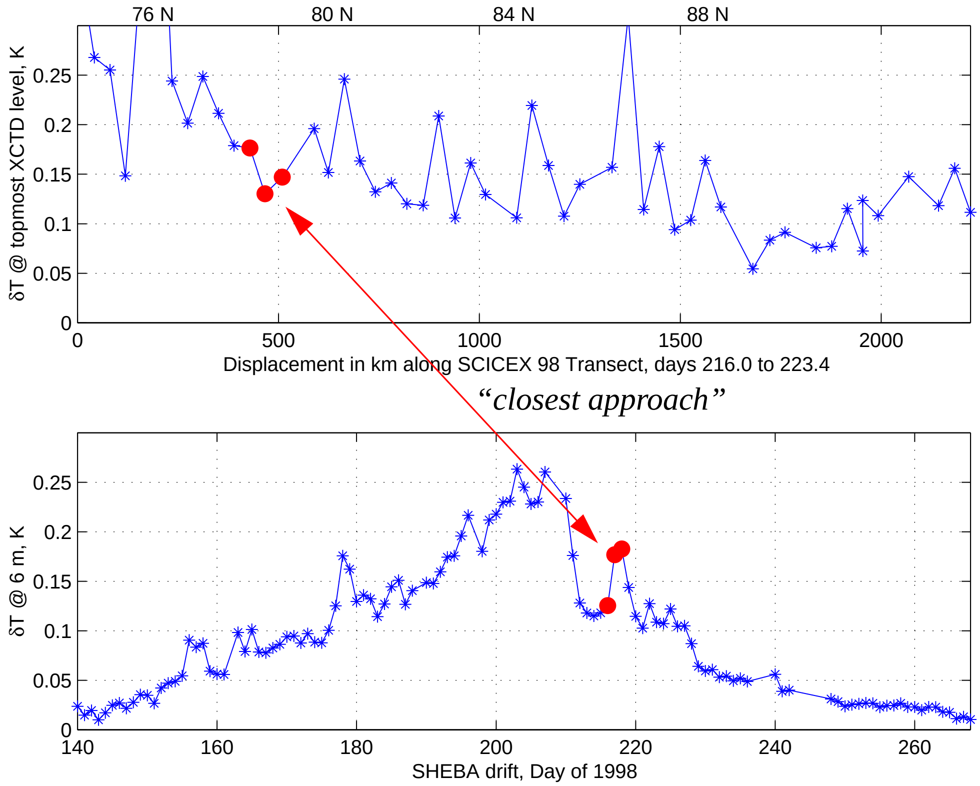

Figure 3. A. "Synoptic" (1 wk) view of the mixed layer δT inferred from XCTD casts during SCICEX 98 transect. Red dots mark casts between 78 and 79 N, at nearest approach to the SHEBA station, on day 217. B. Summer long time series of δT at the SHEBA drift site.

on interpreting a very complex and interesting data set from the SHEBA summer lead study. I continue to work with G. Maykut on SCICEX estimates of heat content and ocean heat flux during the 1998 transect of the USS Hawkbill.

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